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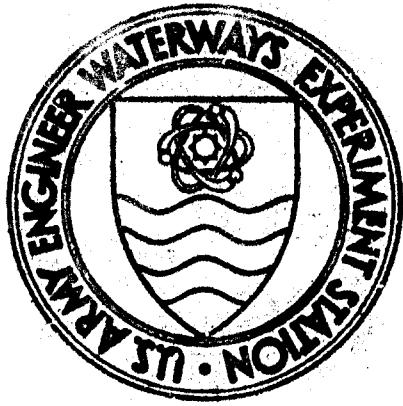
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ADMIXTURES

by

B. Mather

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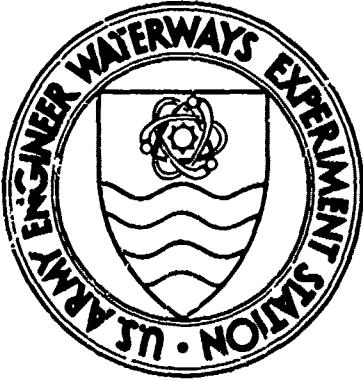
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FOREWORD

The Engineering Foundation convened a research conference on "Rapid Construction of Concrete Dams," which was held at Pacific Grove, California, on 1-5 March 1970. Session IV of the conference was concerned with special cements and admixtures for rapid concrete dam construction. Mr. Bryant Mather, Chief, Concrete Division, was requested to prepare the paper on admixtures for presentation at this session; however, he was unable to attend the meeting and present it. It was presented in his absence by Mr. J. M. Polatty, Chief, Engineering Mechanics Branch, Concrete Division. On the last day of the conference the participants approved a resolution which recommended that the papers, originally prepared as the basis for off-the-record discussions, be published. The manuscript was, therefore, referred for approval for publication to the Chief of Engineers and such approval, subject to certain comments, was granted on 20 May 1970.

Directors of the Waterways Experiment Station during the preparation and publication of this paper were COL Levi A. Brown, CE, and COL Ernest D. Peixotto, C. Technical Director was Mr. F. R. Brown.

69325

ADMIXTURES*

by

Bryant Mather**

Introduction

1.1 The purpose of this Conference is to investigate, in depth, design and construction procedures for reducing the cost of concrete dams. This is a somewhat more restricted purpose than that of the International Commission on Large Dams, which is: "To promote and coordinate improvements in technical research, design, construction, maintenance, and operation of large dams..." More simply stated, the objective of ICOLD is to contribute to the construction and operation of good dams. The objective of engineering, as it relates to concrete for use in dams and appurtenant works, is to insure that the concrete so used is good concrete. Good concrete is concrete that possesses the necessary levels of the properties appropriate to the service demanded of it at all times in its useful life plus a "factor of safety" or "factor of ignorance" sufficient to merit and receive confidence. It is not good engineering to require that concrete have unnecessarily high levels of

* Prepared for presentation as Paper 2, Session IV: Special Cement and Admixtures for Rapid Concrete Dams Construction at 1970 Engineering Foundation Research Conference, "Rapid Construction of Concrete Dams," Asilomar Conference Grounds, Pacific Grove, California, 3 March 1970; presented by James M. Polatty, Chief, Engineering Mechanics Branch, Concrete Division, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

** Chief, Concrete Division, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi 39180.

important properties or any particular level of irrelevant properties, especially when, as will almost always be the case, the inclusion of such requirements increases the initial cost. It is, of course, obviously not good engineering to fail to require--and hence usually not obtain--concrete that does develop the necessary levels of important properties.

1.2 Concrete is not a static, constant, unchanging material. As initially mixed, it is a suspension of solid particles in a liquid. Thereafter, it evolves into a relatively rigid solid that will develop predictable levels of many different properties depending on the properties of the constituent materials used, their proportions, the practices employed in production, and the environment of subsequent maturation and exposure. As designers and builders of dams and appurtenant works develop data on what are the relevant properties of concrete and what are the necessary quality levels of these properties that the concrete must possess in order to render the desired service at all times in its useful life, the concrete technologist will perfect the techniques needed to insure that the proper materials, proportions, and practices are required and obtained.

1.3 The state of knowledge has not yet progressed to the point where the designer knows what he needs, nor can the concrete technologist, with precision, predict the particular levels that will be developed in the properties of a given concrete in a given environment. We do not yet have adequate methods of quantitatively evaluating the pertinent properties of the environment and the significance of different--and changing--levels of these properties on the maturation and exposure of concrete therein.

Properties of Concrete

2.1 Concrete for use in large dams, as initially mixed, must possess a degree of mobility and fluidity, together with a degree of cohesiveness, so that as transported, handled, deposited, consolidated, and finished, it can be discharged into and out of the containers in which it is transported and into its final position in the work without excessive segregation and can there be properly consolidated, and if necessary, finished with the equipment provided to be used for these operations. After placement and consolidation, it must undergo appropriate changes at rates such that, when called upon to resist loads or other environmental influences, it will have the necessary levels of the relevant properties when those are needed, and it must undergo these changes without concurrently developing undesirable levels of other properties--such as excessively high internal temperatures--that are harmful. For example, when cantilever-form-construction techniques are used, the concrete in which form anchors are embedded must develop adequate strength to resist form-anchor pull-out forces at the time the freshly mixed concrete is placed in the next higher lift and thereafter as loads bear on the anchors.

Admixtures for Concrete

3.1 Any material, other than water, aggregates, and hydraulic cement, used as an ingredient of a concrete mixture, added to the batch immediately before or during its mixing, is, by definition, an admixture. Such materials, when interground or interblended with the hydraulic cement, are described

as "additions" to the cement. The purpose of using an admixture is to make the concrete to which it is added more suitable for the purpose for which it is made or available at lower cost. An admixture should not be used unless there are benefits to be obtained that are worth the cost of so doing and are benefits that cannot be obtained by other means.

3.2 Admixtures can be and are being used to modify virtually any property that concrete naturally possesses and are also used to impart properties it could not otherwise have. In some cases, the effect is to change the time at which the concrete develops a given property to a given degree; in other cases, a property is conferred that, without the admixture, could never have been achieved by the concrete mixture. Admixtures have been used for at least 2000 years. Marcus Vitruvius Pollio in the first century A.D. set forth a specification for mortar that called for well-hydrated lime, marble dust, sand, and water, "to which is added either hog's lard, curdled milk, or blood." The two most widely used classes of products employed as admixtures for concrete, organic chemical materials and active mineral powders (pozzolans), were both known to and used by the Romans in classical times.

3.3 Among the effects that are sought by the use of admixtures are the following:

- 3.3.1 Achievement of an earlier setting time (acceleration).
- 3.3.2 Delay of setting time (retardation).
- 3.3.3 Achievement of equal workability with lower water content (water reduction).

3.3.4 Incorporation of a system of entrained air voids in the cement paste (air entrainment).

3.3.5 Removal of excessive amounts of air bubbles from the cement paste (air detrainment).

3.3.6 Reduction of temperature rise due to cement hydration.

3.3.7 Reduction of expansion due to the alkali-silica or alkali-carbonate reaction.

3.3.8 Reduction of permeability of concrete (permeability reduction).

3.3.9 Inhibition or tendency of embedded metal to corrode (corrosion reduction).

3.3.10 Reduction of tendency of concrete to be weakened by leaching.

3.3.11 Reduction of tendency of concrete to segregate and bleeding.

3.3.12 Improved cohesiveness and plasticity, especially in low-cement content mixtures.

3.3.13 Reduction of cost of construction.

3.4 The principal materials used for these purposes are as follows:

3.4.1 Accelerators. The most widely used accelerator is calcium chloride. Other materials which accelerate the hardening of mixtures of portland cement and water include other soluble chlorides; soluble carbonates, aluminates, silicates, fluosilicates, and hydroxides; and some organic compounds such as triethanolamine. Calcium chloride can generally

be used safely in amounts of up to 2 percent by weight of the cement. The benefits of such use are greatest in cold weather, and at high temperatures the effects may be detrimental. Calcium chloride should not be used where stray electric currents are to be expected or in prestressed concrete because of its tendency to promote corrosion of steel. Its use may also aggravate sulfate attack and the alkali-silica reaction. It is convenient to make solutions in which one quart contains one pound of calcium chloride.

3.4.2 Retarders. The commonly used retarding admixtures are organic chemicals, generally lignosulfonic acid salts or hydroxylated carboxylic acid salts or modifications thereof. At normal temperatures, used in normally recommended amounts, the setting time of concrete may be extended 30 to 50 percent. Greater delays of setting can be obtained by using larger amounts. Retarders are usually used to compensate for the undesired accelerating effects of high placement temperatures, to avoid cold joints, and to avoid undesirable effects of displacements and deflections due to loading of forms and supports by subsequent concrete placement. When retardation is obtained, improved consolidation may be achieved by revibration; when revibration is to be employed, retardation is required.

3.4.3 Water reducers. The same basic kinds of materials that are retarders are generally water reducers. Many water reducers are retarders that have been chemically modified to suppress or compensate for their retarding effect. Water reducers have the property of increasing the workability (slump or flow) of the concrete in which they are used. Advantage may be taken of this effect in any of several ways: (a) a concrete mixture deficient workability can have its workability increased with

no change in cement content or water-cement ratio; (b) a concrete mixture of adequate workability can have its strength increased by reducing the water-cement ratio and maintaining cement content and workability unchanged; and (c) a satisfactory concrete mixture can be made more economical by maintaining the water-cement ratio and workability but reducing the cement content or increasing the pozzolan to cement ratio. Water reducers are necessary in the production of very high-strength concretes for which water-cement ratios of 0.35 or lower are required, if the freshly mixed concrete is to have the normally expected workability.

3.4.4 Air-entraining admixtures. The materials used as air-entraining admixtures are those which make foam; they are thus similar to soaps and detergents. They are generally derived from resins, fats, or oils. The primary purpose of air entrainment is to protect the concrete against the damage it may suffer if the paste becomes saturated with water and then freezes. A mature portland-cement paste in which air bubbles are present with a spacing factor of 0.006 in. or less will not be damaged by freezing even if saturated* with water. The spacing factor is the average maximum distance from any point in the paste to the nearest air void. With acceptable air-entraining admixtures, the air-void spacing factor will be within the correct limits if the amount of air-entraining admixture used is such that the freshly mixed concrete contains 9 percent air in the mortar fraction or 5-1/2 percent air in concrete containing aggregate of 1-1/2 in. maximum size. The amount of air-entraining admixture required to produce the

* It is assumed that the entrained-air voids are not filled with water.

specified air content will be greater at higher temperatures, in mixtures containing larger proportions of fine materials, or when materials are used that tend to adsorb organic materials. If an acceptable air-entraining admixture is used in an amount such that the proper air content is developed in the freshly mixed concrete, tests have shown that expulsion from the concrete of a substantial proportion (up to about half) of the total air content by continued vibration does not significantly alter the air-void spacing factor and, hence, does not destroy the protection furnished against frost damage.

3.4.5 Air-detaining admixtures. Cases have been reported in which concrete mixtures made with certain materials, especially certain natural aggregates, contain considerably more entrapped gas bubbles than normal. Such a condition greatly hampers production of air-entrained concrete, since the gas bubbles that are present without any air-entraining admixture are relatively large and ineffective in providing frost resistance. In other cases, it may be desired to use a water-reducing or a retarding admixture that will entrain air, but not to have air entrained in the concrete. In these and similar cases a material such as tributyl phosphate is used as an air-detaining admixture to dissipate and expel the unwanted bubbles of air or other gas.

3.4.6 Pozzolans. The use of a pozzolan as an admixture in concrete will normally permit the use of a smaller cement content per unit volume of concrete than would otherwise be required. In such cases there usually will be a net reduction in heat rise unless the total weight of cement plus pozzolan is substantially greater than the weight of cement.

that would have been used. There will also normally be a savings in cost of concrete materials. Concretes containing pozzolans generally also will have better cohesiveness and plasticity, less tendency to segregate and bleed, reduced tendency to be weakened by leaching, better assurance of long-time sustained strength and protection against excessive expansion due to alkali-silica reaction.

3.4.7 Temperature-rise reduction. The temperature rise exhibited at a point in a concrete mass after placement can be reduced by the use of admixtures only as a secondary effect of the use of a lower cement content in the concrete. As noted under water-reducers, their use may allow use of reduced cement content or increased pozzolan-to-cement ratio. Pozzolans generally permit use of lower cement contents.

3.4.8 Alkali-expansion reduction. Research has shown that internal expansion of concrete resulting from the chemical reaction of the alkalies, Na_2O and K_2O , with various forms of soluble silica and certain carbonate rocks that may be present in concrete aggregates may be reduced by the use of admixtures either of the pozzolan class or certain chemicals such as certain lithium salts. When aggregates that are of such a nature that they might react with alkalies to give deleterious expansions must be used, the cement should be required to contain not more than 0.6 percent by weight of alkalies (percentage Na_2O plus 0.658 percentage K_2O). The most effective method of preventing excessive expansion resulting from the reaction of alkalies with reactive carbonate rocks is insuring that reactive material in the aggregate is uniformly distributed and comprises only a small percentage of the total aggregate used.

3.4.9 Permeability reducers. Materials have been marketed as admixtures that have been described as "waterproofers." Many such materials are of the nature of soaps, oils, or resins which are water repellent and may, by this method, retard the wetting of a concrete or mortar by drops of water that fall on its surface. Most such materials, if employed for this purpose, are used as surface applications to hardened concrete or mortar surfaces. Admixtures have not been found that will prevent the entry of water into concrete or its transmission through concrete. Some admixtures will, however, reduce the permeability of mortars and concrete to water. Permeability reducers are mineral powders that increase the solids contents of lean mixtures and, if they are cementitious or pozzolanic, react to produce additional solids after they are incorporated in the concrete.

3.4.10 Corrosion inhibitors. Iron and steel embedded in concrete will not rust if the metal is kept completely sealed from access to the external environment and the concrete maintains its normal alkaline state (pH greater than 12). Where the possibility of corrosion arises from insufficient cover of concrete over the steel, this cannot be mitigated by the use of an admixture in the concrete except as the admixture may reduce the permeability of the concrete and, hence, increase the effective cover. If, however, the possibility of corrosion arises from reduction of the normally protective chemical nature of the concrete, then use of admixtures to retard or inhibit corrosion is a possibility. Among the materials that have been studied are sodium benzoate, calcium lignosulfonate, stannous chloride, and sodium nitrite.

3.4.11 Cost reduction. The use of admixtures may reduce costs of construction and maintenance in a large number of different ways. In many cases, the use of admixtures will reduce the cost of the constituent materials required to produce a unit quantity of concrete, for example, by allowing concrete of appropriate quality to be produced with a lesser unit quantity of cement. In other cases, the use of admixtures will reduce the cost of construction by permitting more economical scheduling through modification of time of setting of concrete. When, by the use of admixtures, the concrete is rendered more durable and better able to resist potentially destructive environmental effects, maintenance and repair costs are reduced.

Previous Work

4.1 In 1962 the Concrete Committee of ICOLD initiated work toward the preparation of "Recommendations on Admixtures for Large Dams." In 1967 a document dealing with surface-active admixtures (air-entraining admixtures and water-reducing admixtures) was approved and was published in 1968. In 1968 the committee appointed two additional task groups to deal respectively with pozzolans and slags and with accelerators and retarders. Drafts of documents in these areas have been prepared and will be before the committee at its meeting in Montreal in June.

4.2 In 1943 the American Concrete Institute created Committee 212 on Admixtures which produced reports on admixtures in 1944, 1954, and 1963. It is significant, I believe, that the first section of the latest report (ACI Journal, Nov 1963, pp 1185-6) deals with "Economic Aspects of the Use of Admixtures." I quote from this section:

"Use of an admixture may increase or decrease the cost of the concrete. The effect of a given admixture can sometimes be obtained, at least in some degree, by other means or by other admixtures. Whenever possible, the cost of an admixture should be compared with that of alternative materials or methods for getting the desired result. Conversely, the economic gains possible through decreased construction costs by the use of admixtures should also be considered.

"In evaluating an admixture, its effect on the volume of a given batch should be noted. If adding the admixture changes the volume, as is often the case, the change in the properties of the concrete will be due not only to direct effects of the admixture but also to the changes in the amounts (per unit volume) of the original ingredients. If the use of the admixture increases the volume of the batch, the admixture must be regarded as effecting a displacement either of part of the original mixture or of one or another of the basic ingredients--cement, aggregate, or water. All such changes in the composition of a unit volume of concrete must be taken into account when testing the direct effect of the admixture itself, and in estimating the cost of the use of an admixture.

"The cost of handling an extra ingredient, and any effect the use of the admixture may have on the cost of transporting, placing, and finishing the concrete should be taken into account. Frequently an admixture permits use of less expensive construction methods or even of less expensive structural design so as to offset any increase

of cost of materials attending the use of an admixture. For example, novel and economical designs of structural units have been predicated on use of retarding admixtures that permit placing of concrete over extended periods in homogeneous units of large size and great volume, thus minimizing need for forming and the placing and joining of separate units. Use of air-entraining and water-reducing admixtures commonly makes possible the attaining of required physical properties of lightweight concrete at lower unit weight.

"The evaluation of the cost of any given admixture should be based on the results obtained with the particular concrete in question under conditions simulating those expected on the job. This is highly desirable since the results obtained are influenced to an important degree by the characteristics of the cement and aggregate and their relative proportions, as well as by temperature, humidity, and curing."

4.3 In August-September 1967, in Brussels, the RILEM working group on Admixtures sponsored an International Symposium on Admixtures for Mortar and Concrete, the proceedings of which, in eight volumes, have been published. The report of this working group includes the following:

"An admixture is any material that is added to the normally accepted ingredients of mortar and concrete during mixing in order to modify certain properties of mortars and concretes in their fresh or hardened state, or in their passage from the fresh to the hardened state.

"Every admixture must have as its main action a definite purpose in mortar or concrete. It may have simultaneous secondary actions which must also be specified. Admixtures perform their functions principally by affecting physical and physico-chemical actions, such as surface tension, adsorption, thixotropy, colloidal state, deflocculating effects, rate of reaction between cement and water during setting and hardening, and combination with certain cement constituents. Admixture actions of a mechanical nature may also arise owing to the addition of very small particles to the aggregate grading of mortars and concretes.

"In general, admixtures are to be used only when the desired properties, which are sought to satisfy the requirements of the work at hand with regard to execution, quality and durability, cannot be attained by adjusting the composition or the proportions of the basic concrete or mortar mixture. Moreover, information should be available not only with regard to the effect of the admixture on the main property which it is desired to modify, but also with regard to the effects that its use may have on all the other properties of mortar and concrete.

"It should be recognised that the mere use of an admixture can never compensate for defects in the composition or in the preparation of the mortar or concrete."

This working group classifies admixtures as follows:

"1. ADMIXTURES WHICH MODIFY THE RHEOLOGY OF FRESH MORTAR AND CONCRETE."

- 1.1 Water-reducing admixtures.
- 1.2 Air-entraining admixtures.
- 1.3 Water-reducing and air-entraining admixtures.
- 1.4 Plasticising mineral powders.
- 1.5 Flocculating or thickening admixtures.
- 1.6 Water-retaining admixtures.
- *2. ADMITTANCES WHICH MODIFY THE AIR CONTENT OF MORTAR AND CONCRETE.
 - 2.1 Air-entraining admixtures.
 - 2.2 Air-detaining or anti-foaming admixtures.
 - 2.3 Gas-forming admixtures.
 - 2.4 Foam-forming admixtures.
- *3. ADMIXTURES WHICH MODIFY SETTING AND HARDENING.
 - 3.1 Set-retarding admixtures.
 - 3.2 Set-accelerating admixtures.
 - 3.3 Admixtures which accelerate hardening.
- *4. ADMIXTURES WHICH PRODUCE EXPANSION IN MORTAR AND CONCRETE.
- *5. ADMIXTURES WHICH IMPROVE THE RESISTANCE TO PHYSICAL ACTIONS.
 - 5.1 Frost-resisting admixtures.
 - 5.1.1 Air-entraining admixtures.
 - 5.1.2 Admixtures which accelerate setting and hardening.
 - 5.2 Anti-freezing admixtures.
 - 5.3 Water-resisting admixtures.
 - 5.3.1 Permeability-reducing admixtures.
 - 5.3.2 Water-repelling admixtures.

"6. ADMIXTURES WHICH IMPROVE THE RESISTANCE TO MECHANICAL ACTIONS.

"7. ADMIXTURES WHICH IMPROVE THE RESISTANCE TO CHEMICAL ACTIONS.

7.1 Corrosion-inhibiting admixtures.

7.2 Admixtures which modify alkali-aggregate reaction.

7.3 Admixtures which modify attack by aggressive chemicals.

"8. ADMIXTURES WHICH IMPROVE THE RESISTANCE TO BIOLOGICAL ACTIONS.

Fungicidal, germicidal and insecticidal admixtures.

"9. ADMIXTURES WHICH MODIFY THE COLOUR OF MORTAR AND CONCRETE.

COLOURING ADMIXTURES."

Specific Applications to Dca Construction

5.1 In "Research for Civil Works - A Progress Report" (Office, Chief of Engineers, Dec 1968), the following are shown as reductions in cost, relating to the employment of admixtures in concrete.

<u>Problem or Study</u>	<u>Solution or Result</u>	<u>Savings</u>
Low Cement Content Concrete		
The hydration of cement produces heat which is not readily dissipated in mass concrete. The temperature change produced by this heat and subsequent cooling is a cause of cracking which impairs the structural integrity of hydraulic structures. Furthermore, cement is the most expensive ingredient of concrete. Any saving of cement without sacrifice of quality produces a substantial financial benefit.	Laboratory studies of mixture proportioning established that, primarily through the use of entrained air in an application in which it had not previously considered, it was possible to reduce the cement content of mass concrete as much as 30 per cent without impairing its quality.	\$10,600,000

<u>Problem or Study</u>	<u>Solution or Result</u>	<u>Savings</u>
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Cement Replacement Materials

Portland cement is the most expensive ingredient of concrete. A significant saving in the cost of concrete would be realized if a portion of the cement could be replaced by a less expensive cementitious material without sacrifice of quality.

A laboratory investigation established the validity of using pozzolans and special cements as partial replacement for portland cement and produced a workable specification for purchasing pozzolans.

\$9,600,000

Use of Concrete Admixtures

To evaluate the claims of producers of chemical admixtures intended to retard the setting of cement, increase workability of concrete, and provide other benefits.

Specifications have been developed to assure reliability, and guides produced for limiting use to instances where real benefits will exist.

Intangible.
Assures usage of only those admixtures which will produce better concrete.

Pre-Placed Aggregate Concrete

Because of shrinkage during setting and difficulty of placing in restricted regions, conventional concrete is not always entirely satisfactory for such applications as embedment of steel spiral cases in powerhouses, construction of plugs to close temporary sluices through dams, and underwater construction, or for major repair of concrete structures.

A laboratory investigation, which included tests of full scale models of portions of hydraulic structures, established the value of the pre-placed aggregate method of construction. On some projects savings in excess of \$200,000 have been realized by its use. In other projects it has been used, even though more expensive, to improve the performance of the structure. The figure shown is the net saving.

\$17,300 annually

5.2 The work related to these savings was described as follows:

"Low Cement Content Mass Concrete. To reduce initial construction costs and cracking caused by cooling from elevated temperatures produced by cement hydration, mass concrete should contain a minimum of cement consistent with strength, permeability, and durability

requirements. Mixture proportioning studies coupled with strength, permeability, and durability testing demonstrated that approximately 30 percent of the previously specified unit amounts of cement per unit volume of concrete could be eliminated in future construction. The primary factor which permitted this savings was the use of entrained air in mass concrete. In establishing the validity of the savings permitted, it was necessary to develop appropriate procedures for testing mass concrete for durability and permeability.

*Use of Pozzolans in Mass Concrete. Pozzolans are not in themselves cementitious but will react with the lime produced as a hydration product of portland cement to form cementitious compounds. The most common pozzolan is flyash, the residue from burning powdered coal in thermal power plants. Some natural materials, mostly in the western part of the country, are also pozzolanic or become pozzolanic after burning and grinding. Since pozzolans are cheaper than cement and generate less heat, their use as a partial replacement for cement in mass concrete is attractive. Research shows that their use is practical and a workable and reliable purchase specification has been developed. Pozzolans are now widely used in the field. A recent laboratory experiment involves the use of only one bag (94 lb) of cement per cubic yard of concrete with relatively large amounts of pozzolan. If this development can be applied successfully in future construction, substantial monetary savings will result. Test blocks typically 5 x 10 x 20 ft in size are made, exposed out of doors, and cored by diamond drilling equipment to yield specimens for detailed laboratory testing and examination.

"Use of Retarding and Water Reducing Admixtures. Cheap chemicals from the paper industry and other sources are used extensively in structural concrete construction to control setting time, increase strength, and reduce the amount of mixing water and cement required. Application of such admixtures to the very low cement factor mass concrete used by the Corps of Engineers is currently being studied. If a reduction in cement or a reduction in the ratio of cement to pozzolan is possible, financial savings will result.

"Portland Blast-Furnace Slag Cement. Information was developed which demonstrated that high quality concrete for hydraulic structures can be produced with portland blast-furnace slag cement as well as with portland cement. This finding has increased the bidding options for contractors and, in certain market areas, is resulting in lower bid prices."

5.3 In this same report, future concrete research was described in these words.

"Concrete. Much of the research in mass concrete will continue in the future, as it has in the past, to be concerned with temperature problems resulting from hydration of cement. At present hydration of cement is studied under isothermal conditions, and temperature rise in concrete is studied under adiabatic conditions. The information, however, is applied to conditions, which are neither isothermal nor adiabatic. More information is needed to make

possible accurate predictions of temperature rise under field conditions. There is a pressing need to determine the effect of temperature on creep of concrete. Recent work in Europe and Israel suggest that creep increases as a result of temperature fluctuation regardless of which way the temperature is changing. These findings need to be clarified and their application to mass concrete hydraulic structures evaluated.

"The field of chemical reactions between cement and aggregates, once thought to be non-existent, requires additional study. The reaction between cement alkalies and certain siliceous rocks is now well understood. The reaction involving dolomitic carbonate rocks is now under active investigation. A reaction in which non-dolomitic carbonate rocks participate has recently been discovered by personnel at the Waterways Experiment Station. The implications of this discovery are not yet known. A cement-aggregate reaction involving materials in the Kansas-Nebraska area has been evident for years, but it is not yet understood. The Corps of Engineers builds structures in all the areas in which these reactions have been observed.

"In addition to the chemical reaction between cement paste and aggregates, there are physical reactions which are not well understood. Although cement paste and aggregate have been extensively studied separately, little is known about the nature of the bond between these two basic components of concrete. This bond is a key factor both in the problems of strength and cracking.

"Expansive cements may have a bright future in the concrete industry. They have been proposed both for compensating for shrinkage of concrete and for chemical prestressing of concrete members. Only shrinkage compensation has received much attention in this country. Chemical prestressing might offer a means for solving the problems of cracks in concrete structures.

"Few really significant changes in mass concrete construction techniques have occurred in recent years. Such proposals as gang vibrators and precast concrete forms should be investigated. Improved field testing techniques are also needed. There is, for example, no accepted method for measuring the workability of mass concrete.

"Deformations, stress, strain, hydrostatic pore pressures, and temperature changes in massive concrete structures will continue to be measured. With this information the designer is able to improve and refine design criteria and techniques."

Promising Uses of Admixtures to Reduce Cost
and Increase Speed of Construction of Concrete Dams

6.1 From the material reviewed up to now in this paper, it is clear that, by the use of admixtures, nearly any desired property of concrete may be modified at least quantitatively--in either direction--and, in some cases, affected qualitatively as well. The increased use of admixtures therefore depends essentially solely on knowing what properties and what levels, quantitatively, of these properties are

desired and then straightforwardly evaluating the economics of the case. How much is it worth to increase or decrease a given parameter by a given amount, and can this be accomplished more economically by using a given amount of a given admixture than by any other means? In addition, there is always the question of simple alternative solutions to the present set of requirements, i.e., we now require concrete of given properties, we now obtain this concrete by the use of given ingredients, can we by different methods involving use of other admixtures or greater amounts of admixtures produce concrete of these same levels of quality in these same properties more economically.

6.2 In this latter case, work at the Waterways Experiment Station has shown that, at least in the laboratory, it is possible to produce 6-in. aggregate mass concrete with 73 lb of cement per cubic yard, having a water content of 11.5 lb per cubic yard, that has an adiabatic temperature rise of only 17 degrees F in 2^f days and develops a 90-day compressive strength of 3000 psi. This particular mixture was proportioned to contain three different admixtures: It contained 116.5 lb per cubic yard of a pozzolan (fly ash), 2.2 ml per cubic yard of an air-entraining admixture-- which gave an air content of 6.4 percent in that portion of the mixture passing the 1-1/2 in. sieve, and 0.50 percent by weight of the cement plus pozzolan of a water-reducing chemical admixture of the lignosulfonate class. The slump was 1-1/2 in. This is an example of results to be obtained when no particular change in requirements is involved.

6.3 In connection with the planning for this meeting, Mr. James D. Piper told me of work being done at the American Cement Corporation,

described to him by Mr. Walter H. Price in which by the use of an admixture a concrete containing 1/2-in. maximum size aggregate requires about the same amount of water to produce a 3-in. slump as is normally required for concrete containing 6-in. maximum size aggregate. The concrete containing the 1/2-in. aggregate can be continuously mixed in a pug mill mixer and satisfactorily pumped through pipe. For use in a concrete dam, the pipe could be refrigerated and the concrete spread over the top of a block by moving the pipe or a hose attached to the end of the pipe. No vibration would be required to level the concrete, which has a comparatively high one-day and ultimate strength. Because of the low water content, the unit weight of the concrete is about the same as for 6-in. maximum size aggregate concrete.

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